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A PROBABILISTIC APPROACH TO
ASW DEPLOYMENT IN
SHALLOW WATERS

by

Zafer Mutlu Aktan

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A PROBABILISTIC APPROACH TO ASW DEPLOYMENT IN SHALLOW WATERS

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ABSTRACT

The Advanced Air Deployable Array (AdDA), which is a modern air-dropped fiber optic ASW device, provides an opportunity for the rapid enclosure of a hostile submarine in shallow waters. This thesis explores the effect of the deployment depth, and the effect of using longer or shorter AdDA array segments, on the performance of eight proposed AdDA deployment tactics which employ single or dual aircraft. It is shown that when the AdDA sinking rate is considered, several of the proposed tactics become infeasible for certain depth and submarine speed combinations. Still, today fiber optics offer unique capabilities for solving some of the U.S. Navy's and the Turkish Navy's problems in the future.

TABLE OF CONTENTS

I. INTRODUCTION

This thesis examines the deployment of Antisubmarine Warfare (ASW) assets in shallow waters, with the emphasis on the use of a modern air-dropped ASW device called the Advanced Air Deployable Array (AdDA). In particular, deployment tactics for its use in the shallow waters surrounding the Turkish Straits will be explored.

A. GEOPOLITICS AND TURKEY

Turkey is situated in a very critical environment. Paradoxically, its location increases its value from the strategic point of view, and constitutes a vital contribution to the Western Security. Turkey occupies a crucial area as shown in Figure 1, at the intersection of Asia, Europe, and Africa, and, together with Germany, the Arabian Peninsula, the Persian Gulf, India and China, it is situated on the geopolitical belt that Halford Mackinder [Ref.1] called the "Inner Crescent".

As natural bridges between Europe and Asia the Turkish Straits have a significant strategic importance in this part of the "Inner Crescent". All the natural sea, land, and air routes from the Black Sea to the Mediterranean and from Balkans to the Persian Gulf lead across Turkey and through the Turkish Straits. The Bosphorus and the Dardanelles are still

the gates to world for some of the republics in the Commonwealth of Independent States like Russia and Ukraine. More than one hundred ships from, or en route to, the countries in the Black Sea region use the straits daily. Any kind of hostile action to the straits will also affect the other countries in the region.

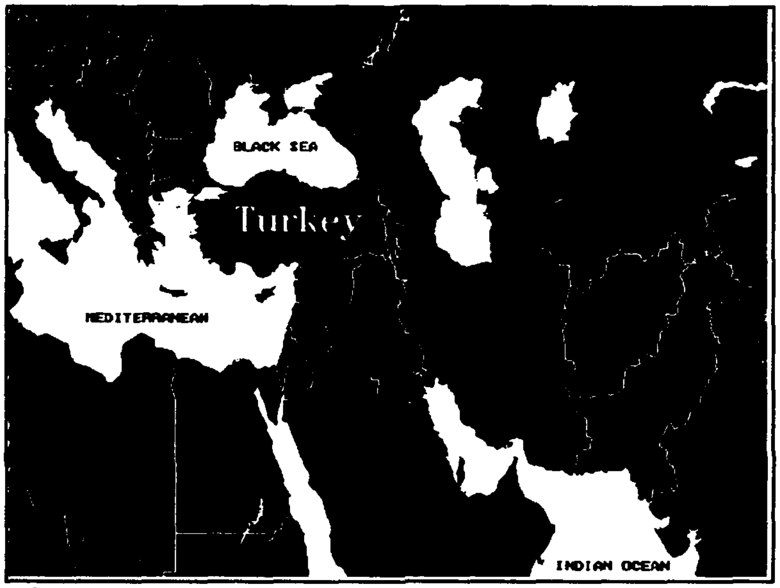

Figure 1. Turkey is a natural bridge between Europe and Asia

B. THE SHALLOW WATER DEFENSE ZONE (SWDZ)

Much of the water surrounding the Turkish Straits is shallow, and an important consideration is the defense against submarines in this shallow waters. Because of their sneak attack capability, submarine's participation in hostile actions in the vicinity of the straits is quite possible. Their participation in such actions will be highlighted in the next section.

Due to the new Air Defense Initiative Architecture, the definition of the shallow water changed from 100 fathoms of depth or less to 200 fathoms or less [Ref.2:p.2]. This definition will also be used in this thesis.

Although the Shallow Water Regions which lie just outside of the Turkish Straits in the Black Sea and the Aegean Sea are both of interest, the one in the Black Sea will be the focal region for this study. Figure 2 shows both shallow water regions surrounding the Turkish Straits (Bosphorus and Dardanelles).

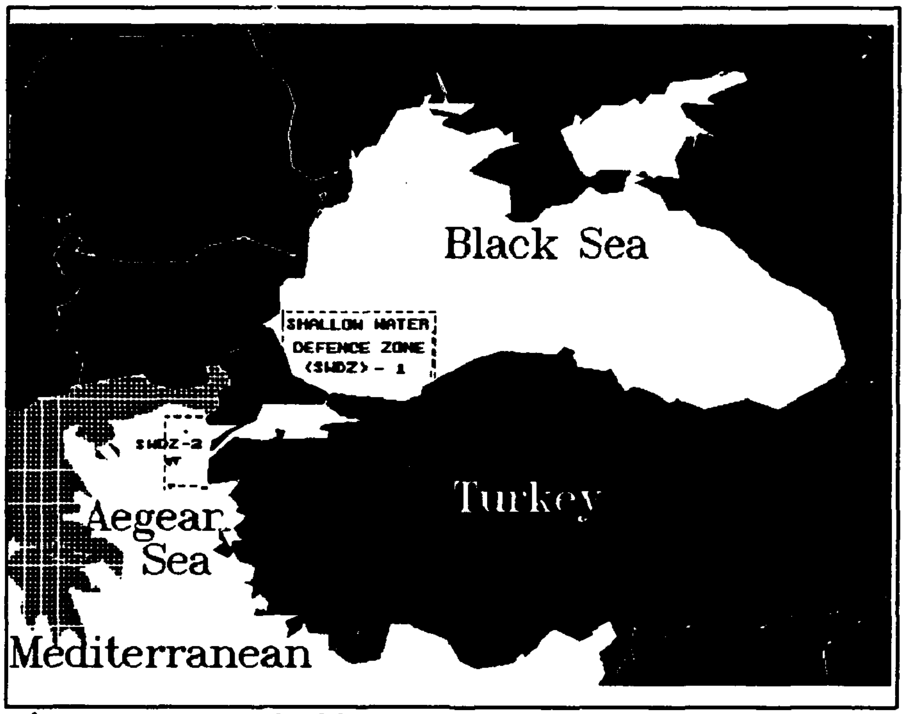

Figure 2. Shallow Water Defence Zones

The proposed and revised deployment tactics, which will be given later in Chapter III, will pertain to the shallow water region in the Black Sea. The distance of the 200 fathom

line from the coast is not uniform in this region, but for the ease of the analysis the region will be thought of, and modeled as, a rectangular strip. In this study the shallow water regions are called "shallow water defense zones (SWDZ)", because of the nature of the problem.

C. NATURE OF THE PROBLEM

As nuclear missile platforms, submarines are always a threat. They can also be used to carry mines or specially trained commando groups to shallow waters and coastal regions. In World War II the German submarines constructed minefields along the Eastern U.S. Coast. For example, U-701 planted mines on 12 June 1942 at the entrance of Chesapeake Bay in Virginia. This minefield sank two ships and heavily damaged two others five days later [Ref.3:p.246-258].

The same danger is still present. Today's more sophisticated, faster and quieter submarines can reach greater distances in shallow waters when submerged. The presence of unknown minefields deployed to control the Bosphorus exit would act like a trap for Turkish and Allied Navies, and could cause delays in supporting a possible force in the Black Sea Region.

In this respect, early detection of an enemy submarine is critical, and reaction time is important. If the deep water surface ASW assets lose the submarine contact as the hostile

submarine enters shallow water, the air deployable array can often be used to regain it.

D. THESIS OBJECTIVE

The purpose of this thesis is to explore the effect of deployment depth, and the effect of using shorter or longer cables on the performance of the tactics, which are proposed for the deployment of modern ASW assets in shallow waters. Also the most effective deployment pattern among alternative deployment patterns, and the most effective deployment platform (C-130 and CH-53) will be explored for the Advanced Air Deployable Array, which is a modern air-dropped ASW device. During the study these questions will be answered:

1. What will be the effect of the average depth of the deployment area on the effectiveness of the proposed tactics?
2. What will be the effect of using longer or shorter array segments in the deployment tactics?
3. Which deployment platform (C-130 or CH-53) gives better performance in the AdDA deployment tactics?
4. How can we probabilistically compare the proposed deployment tactics?

E. THIS THESIS

In the following chapter we will describe the Advanced Air Deployable Array and summarize previous work that has been done on methods for its deployment. In the third chapter we will discuss different deployment patterns and detection

probabilities of a submarine with the help of these patterns, and compare them by using such MOE's as probability of detection, localization area, and number of arrays required. Also, in the third chapter we will examine the effect of deployment depth on the detection probability of the AdDA deployment pattern. The last chapter will give basic conclusions and recommendations from this study.

II. BACKGROUND AND PREVIOUS WORK

In this chapter we will describe the Advanced Air Deployable Array and summarize some previous work that has been done for its use in shallow waters. We will also indicate some important points that could add to the previous study [Ref.2], as a starting point to the work which will be described in later chapters.

A. AIR DEPLOYED, OVER-OCEAN FIBER OPTIC CABLES

The invention of low-loss fiber in 1970 by the Corning Glass Works, has added a new research dimension for fiber optic cables. Fiber optic cables have some distinctive features [Ref.4:p.8-9], which are not found collectively in other transmission media. These include:

- Small size,
- Light weight,
- Good flexibility,
- Low loss,
- Broad bandwidth,
- Very large information-transmitting capacity per unit cross-sectional area of the fiber cable,
- Freedom from electromagnetic induction,and
- Very little cross-talk.

In this study, we are interested in military applications for fiber optic cables, rather than their technical properties. For example, one of the applications resulting from the features of low-loss and wide bandwidth, is submarine cable. Here the development of long-distance optical fibers and electro-optical components have made new approaches for ocean-laid telemetry systems possible.

Today fiber optics offer unique capabilities for solving some of the U.S. Navy's and the Turkish Navy's possible tactical problems in the future, as well as offering new lightweight cables, which are more easily deployed from an aircraft, flying at certain speeds for strategic surveillance. The Naval Ocean System Center, Hawaii Laboratory, has been concentrating its research efforts on these long-distance air-deployable fiber-optic cable applications [Ref.5:p.87]. One such application being investigated at the Naval Ocean Systems Center is an air deployed fiber optic system utilizing a small diameter, fiber optic communication cable, which is 1600 kilometers in length. A shorter fiber-optic cable, called an Advanced Air Deployable Array (AdDA), was designed and planned for submarine detection in shallow waters as a part of the Air Defense Initiative Architecture (ADI). The Air Defense Initiative Architecture, which commenced in mid-1985, and basically considered the defense of North America [Ref.2:p.1], can also be applied to the defense of the shallow waters surrounding the Turkish Straits. Different air deployment

patterns for the Advanced Air Deployable Cable to regain a lost enemy submarine contact in the shallow water defense zones surrounding the Turkish Straits will be discussed later in Chapter III. Figure 3 shows a basic design picture [Ref.2: p.1] of the Advanced Air Deployable Array.

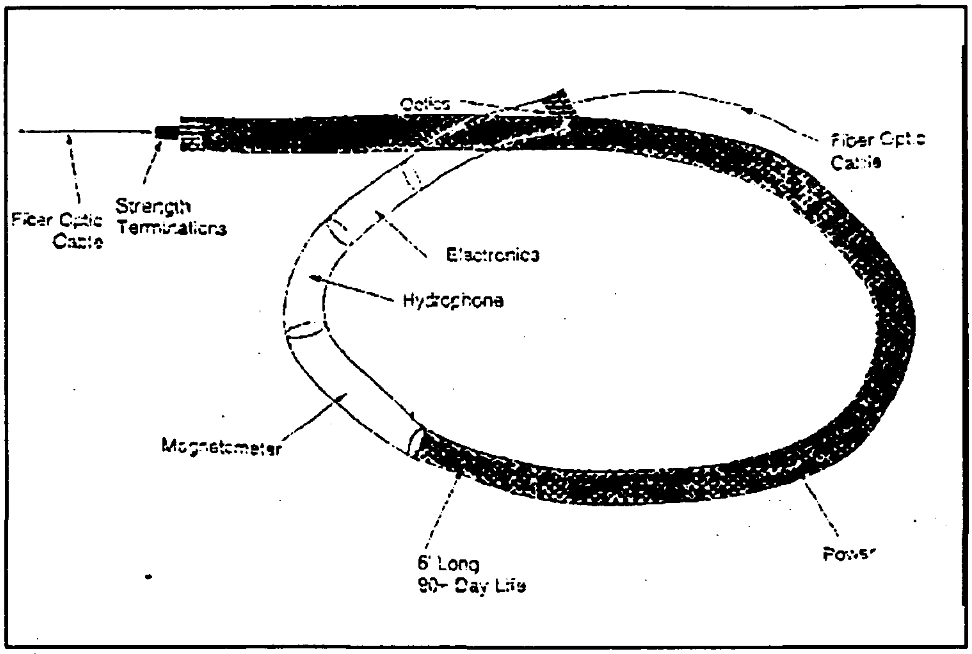

Figure 3. Representation of one Flexible Node of the AdDA

B. METHODOLOGY OF PREVIOUS WORK

The purpose of a previous study [Ref.2] was to investigate tactical employment options for air deployment of the AdDA in detecting an enemy submarine trying to intrude on the eastern U.S. coast. These tactical employment options with two different aircraft types (C-130,CH-53) as deployment platforms were compared using three measure of effectiveness. They are listed below.

1. AREA OF ISOLATION: It is desirable to isolate the enemy submarine in the shallow water defense zone (SWDZ) in an area as small as possible.

2. NUMBER OF ARRAYS REQUIRED: The number of array segments differs due to the AdDA deployment tactic which is used.

3. ISOLATION EFFICIENCY COEFFICIENT: To combine the area of isolation and the number of arrays required to isolate the area, this coefficient is used. The isolation efficiency coefficient displays a measure of increasing effectiveness as its value increases. This MOE will be addressed as <u>Isolation Efficiency</u> (IE) in this thesis, and is given in equation form as:

$$IE = \left(\frac{1}{(Isolation\ Area\ ) * (Number\ of\ Arrays\ Required\ )}\right) * 1000.$$

These MOE's [Ref.2:p.8-9] will be examined in more detail in Chapter III.

C. AdDA DEPLOYMENT TACTICS

In the previous study [Ref.2], proposed AdDA deployment tactics were classified as <u>single</u> and <u>dual</u> aircraft tactics according to the number of deployment platforms. These tactics were also compared for use with two different types of aircraft, the C-130 and the CH-53. In this section these deployment tactics will be summarized, and their graphical representation will be given. (Their numerical analysis will be done later in Chapter III, and the results of the previous study will be given later in Appendix A). Also in this section, opportunities to clarify and embellish the proposed tactics, will be highlighted. The six proposed tactics in the previous study were:

- Arbitrary 50 NM Placement (for both single and dual aircraft),
- Box the Farthest-on Region (for both single and dual aircraft),
- Bound the Expanding Farthest-on Circle (for single aircraft),
- Rapid Enclosure of the Farthest-on Region (for dual aircraft),
- Deep Water Envelope Parallel Enclosure (for dual aircraft), and
- Triangular Cap (for dual aircraft).

Each of these will be described in the following sections. In the figures which follow, the last known location of the submarine is called the lost point, or datum. In this thesis it is assumed that the deep water ASW assets have lost contact with the hostile submarine at the shallow-deep water partition and informed the shallow water defense ASW assets. Therefore, in the following figures, the straight line on which the lost point is situated represents the 200 fathom curve tangent line (this number comes from the definition of the shallow water region [Ref.2:p.2]), and will be called the Shallow Water Defense Zone Border Line (SWDZBL) in this thesis.

1. Arbitrary 50 NM Placement

In the previous study the Arbitrary 50 NM Placement tactic was proposed for both single and dual aircraft. For a single aircraft the tactic can be summarized as follows.

1. The plane flies to a point, which is on the SWDZBL and also 50 NM away from the lost point (Datum), as its deployment starting point.

2. The plane deploys the first AdDA array away from the starting point perpendicular to the SWDZBL, and then deploys the other arrays until the entire width of the shallow water defense zone is spanned.

3. After the last array deployed on this course, the plane flies to a point on the SWDZBL, 50 NM away from the lost point (datum), on the opposite side from the deployment starting point. Then the plane deploys the AdDA arrays as in the same manner of the first span.

For dual aircraft using this tactic, aircraft fly simultaneously to the starting points, and deploy the AdDA array as indicated in Step 2 above. Figure 4 graphically shows this tactic.

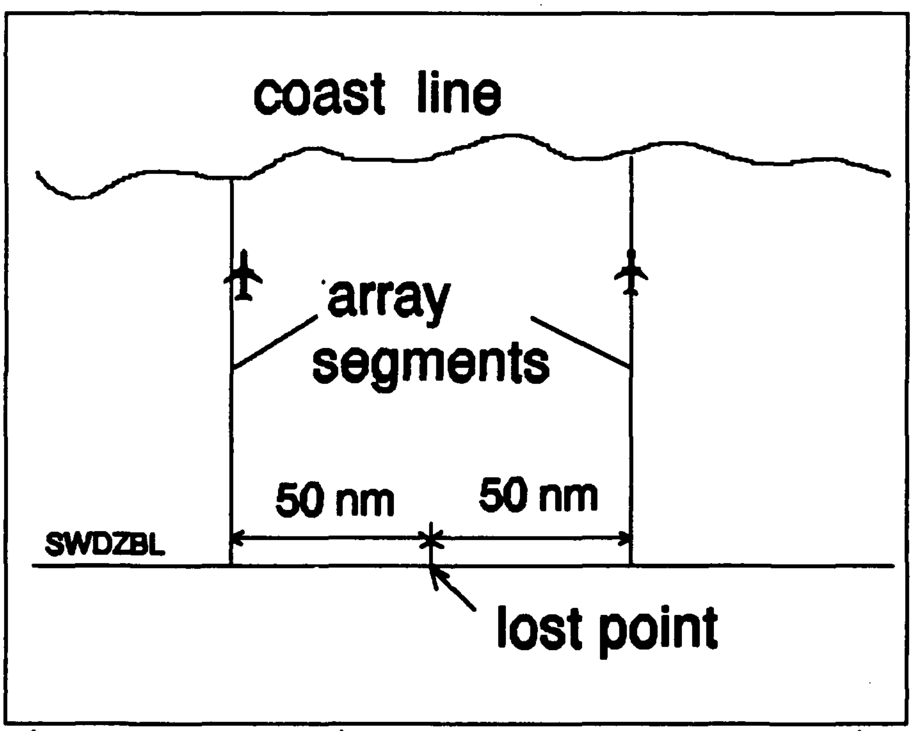

Figure 4. The Arbitrary 50 NM Placement Tactic

2. Box The Farthest-On Region

The tactic of boxing the farthest-on region was also proposed for both single and dual aircraft, and is similar to the Arbitrary 50 NM Placement. The only difference in this tactic is that the starting point is not 50 NM away from the lost point. Basically, the distance d between the starting point and the Datum is the maximum distance that the submarine can travel while the planes fly to their starting points <u>and</u> deploy their first AdDA arrays. For a single aircraft this distance is different on both sides of the lost point (datum), with d1 less than d2, while for two aircraft the distances are approximately the same. A graphical representation of this tactic for single aircraft is given in Figure 5.

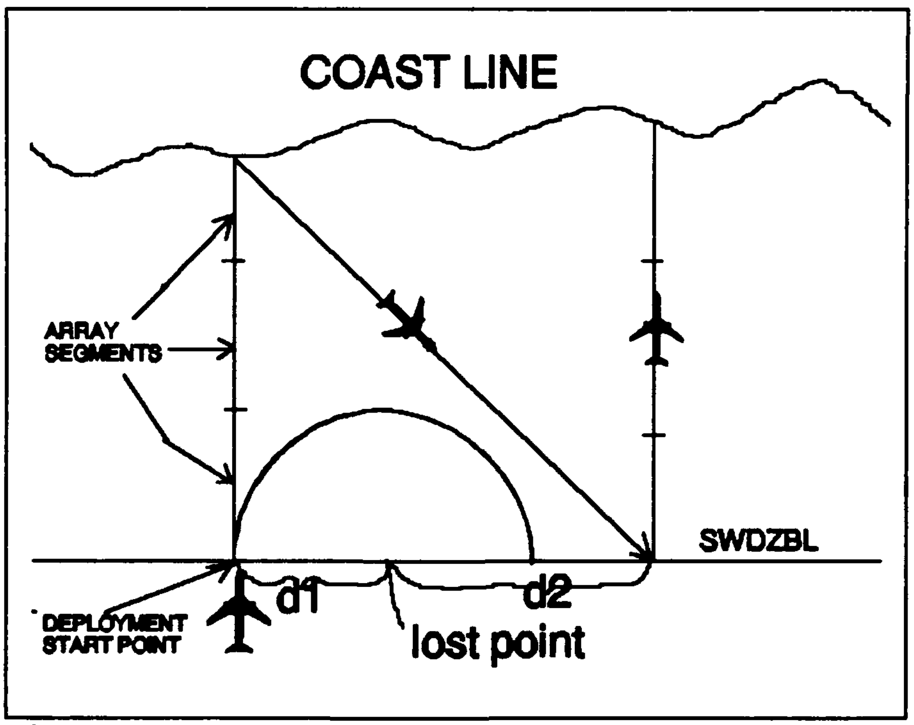

Figure 5. The Box The Farthest-On Region Tactic

3. Bound the Expanding Farthest-On Circle

The bounding the expanding farthest-on circle tactic was proposed only for a single aircraft, and can be summarized as follows.

1. The plane flies to the deployment starting point. The distance d1 between the starting point and the lost point is the maximum distance that the submarine could travel during the flight to the starting point and the deployment of the first AdDA segment.

2. The n^{th} farthest-on circle represents the greatest possible distance from the lost point that could be travelled by the submarine during the flight to the starting point and the deployment of n arrays.

3. The first array will be deployed perpendicular to SWDZBL.

4. After the deployment of the first array segment, the rest of the AdDA array segments will be deployed so that the end of the N^{th} array will be a point on the (N+1)st farthest-on circle of the submarine [Ref.2: p.16].

5. If we denote the AdDA cable length with L, the submarine speed with S_c, and the time for deploying an AdDA array segment with T_d then the sufficient condition for this tactic to work can be written as: $(d1 + 2S_c T_d) < 2L$.

Figure 6 shows a graphical representation of this deployment tactic.

4. Rapid Enclosure of Farthest-On Region

The tactic Rapid Enclosure of the Farthest-On Region was proposed for dual aircraft. It can be summarized as follows.

1. Both planes fly to their deployment starting points located a distance d from the lost point, as explained in the tactic "Box the Farthest-On Region".

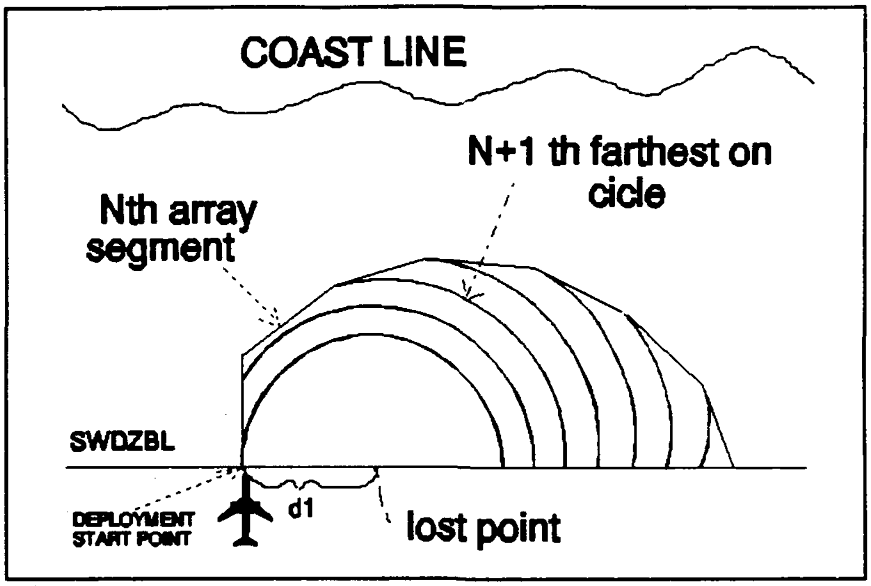

Figure 6. The Bound the Expanding Farthest-On Region Tactic

2. They begin to deploy the arrays perpendicular to the SWDZBL.

3. They cease the perpendicular deployment and begin to deploy the arrays parallel to the SWDZBL, and complete the deployment before the submarine reaches this barrier (thus this tactic is called the rapid enclosure of the farthest-on region tactic).

Figure 7 shows a graphical representation of this deployment tactic.

5. Deep Water Envelope Parallel Enclosure

The Deep Water Envelope Parallel Enclosure tactic is also for dual aircraft. The starting point is different than it is in the previous tactics. It lies on the intersection of the initial farthest-on circle and the line, drawn from the

lost point, perpendicular to the SWDZBL [Ref.2:p.18]. The planes start from this point and deploy arrays parallel to the SWDZBL. After they establish a barrier parallel to the SWDZBL, the planes will deploy the arrays at an angle to enclose the farthest possible progression of the submarine [Ref.2:p.19]. Figure 8 shows a graphical representation of the tactic.

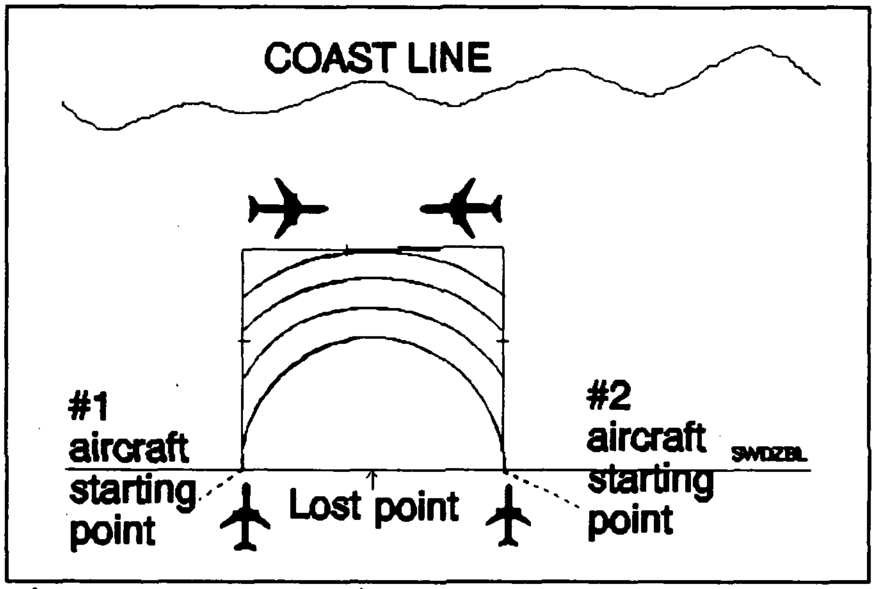

Figure 7. The Rapid Enclosure of Farthest-On Region Tactic

6. Triangular Cap (Tricap)

The dual aircraft tactic Tricap was intended to place arrays so that an isosceles triangle is formed and encloses the submarine [Ref.2:p.19]. The line, which connects the deployment starting point to the lost point (datum), is perpendicular to the SWDZBL (the distance between the starting and the lost point can be found by using Equation 19, which

will be given later in Chapter III). Figure 9 shows a graphical representation of this tactic.

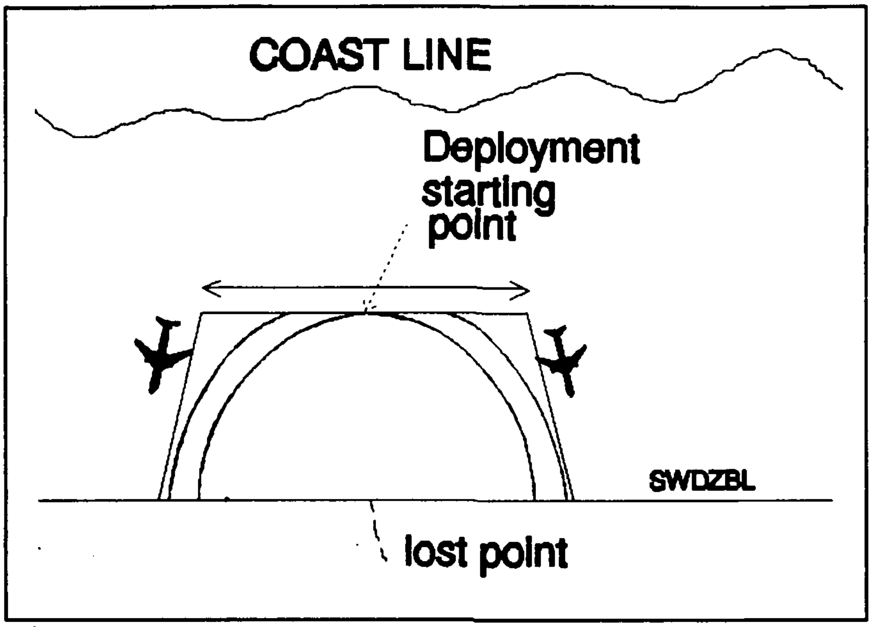

Figure 8. The Deep Water Envelope Parallel Enclosure Tactic

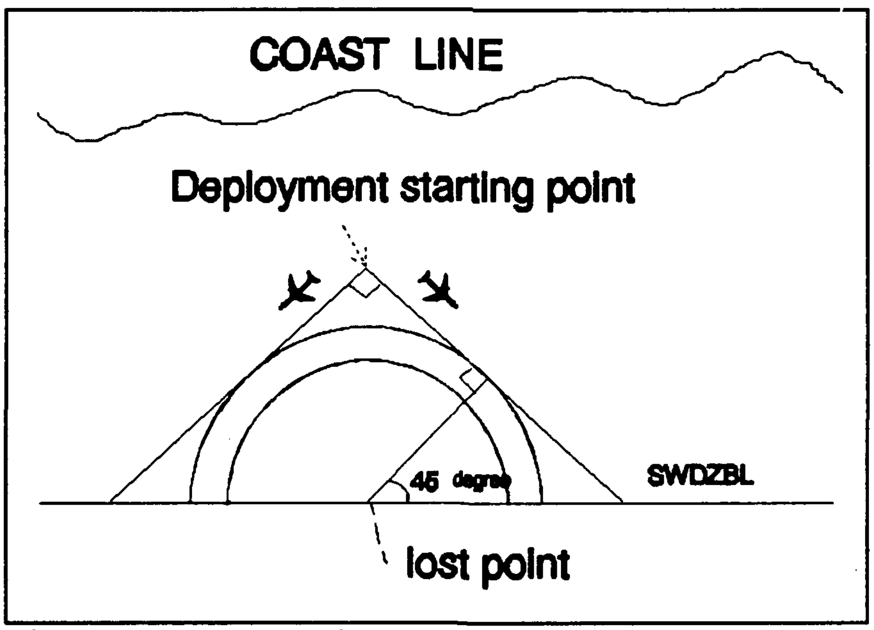

Figure 9. The Triangular Cap Tactic

7. Comments on the Proposed Tactics and Their Analysis

A number of these proposed tactics have intuitive merit. In considering them we will highlight some important points, which will help us to clarify and embellish the previously proposed aircraft tactics.

If the target of the submarine is within the boundaries of the area enclosed by the deployment, then the submarine can complete its mission before detection by the ASW assets. In an Arbitrary 50 NM Placement, if the distance that the submarine can travel by the time an aircraft arrives on station is greater than 50 NM, then this tactic clearly cannot guarantee that the submarine will be bounded in shallow water. Also, use of this tactic in different environments requires consideration of the critical mission of the submarine. In this thesis it is assumed that the submarine's mission is either constructing a minefield in the vicinity of the Bosphorus exit to the Black Sea, or carrying specially trained commando groups to the shoreline in this region. For either mission, the distance that would be travelled by the submarine between the lost point and its destination is almost equal to the width of the shallow water defense zone (SWDZ). Because blocking the forward progress of the submarine is not considered in the Arbitrary 50 NM Placement tactic, there is a high possibility for the submarine to reach its destination and complete its mission without detection by AdDA cables.

This is also true for the single and dual aircraft AdDA deployment tactic called "Box the Farthest-on Region".

After deployment of a cable segment begins, it takes quite a bit of time for it to reach the sea floor, and it is not activated until it sinks completely. For a similar cable the sinking rate is given as 0.044 meters/second [Ref.5:p.88], so that in 200 fathoms the cable would require 2.3 hours to completely sink, delaying activation. This delay in activation time will influence the performance of all of the proposed AdDA deployment tactics, and may change their description. For example, in the boxing the farthest-on region tactic, the distance d1 (determining where deployment begins) <u>should</u> consider how far a submarine can travel while:

1. The deployment aircraft flies to the starting point to begin deployment of the first cable length (AdDA array segment),
2. The first cable length is deployed, and
3. The first cable length completely reaches the bottom and is activated.

Sinking rate should be taken into consideration; its effect on the proposed tactics will be examined in Chapter III, <u>Array Deployment Patterns and Their Effectiveness</u>.

The average depth in the vicinity of the deployment area in the SWDZ may affect both the time for the cable to reach the sea floor and the detection probability of the cable. The effect of depth on the detection probability of the

cable will be explained in Chapter III, Section D. The detection probability of the AdDA was accepted as 1.0 throughout the first study. Although the design of the cables which are very similar to AdDA gives an 30-120 days of estimated lifetime [Ref.5:p.87], the reliability of the cable can be affected to some extent during or after the deployment procedure.

For all five of the proposed <u>dual</u> aircraft AdDA deployment tactics in the previous study, the deployment beginning times for each aircraft are assumed to be the same. Each of the aircraft could come to the initial deployment point from a different base. This could result in an early deployment start for one of the aircraft and possibly affect the performance of the proposed deployment tactic. The same situation can also occur if both aircraft come from the same base, but one takes longer than the other to get airborne. In this thesis, for dual aircraft tactics, it is assumed that both aircraft arrive their starting point almost at the same time.

D. THE NEXT CHAPTER

In the next chapter, the effect of the deployment depth and of cable (AdDA array segment) length on the performance of the proposed deployment tactics will be explored.

III. ARRAY DEPLOYMENT PATTERNS AND THEIR EFFECTIVENESS

In this chapter we will explore (1) the effect of the depth in the AdDA deployment area, and (2) the effect of using longer or shorter fiber optic cables on the proposed AdDA deployment tactics. Additionally, the effect of the deployment depth on the detection probability of an AdDA deployment pattern will be examined in Section D. The results of the previous study, where depth was not considered [Ref.2:p.11], are summarized in tabular form in the Appendix.

A. INPUTS AND ASSUMPTIONS

Continuing the notation used in the previous work [Ref.2] will help to make comparison between the studies easier. The variables used in this analysis are as given below:

- S_e : The speed of the enemy submarine in the shallow water defense zone,
- S_t : The cruising speed of the aircraft while travelling to the deployment area (given in Table 1 for both aircraft types),
- S_d : The AdDA deployment speed of the aircraft (given in Table 1 for both aircraft types),
- T_d : The time to deploy one AdDA array segment,
- T_{sk} : The sinking time of the array segment to the sea floor,
- T_s : The time it takes the aircraft to arrive at the array deployment starting point once the submarine starts travelling from the Datum (lost point), where the Datum

can be defined as the last known location of the hostile submarine,

- L : The length of an array segment, and
- W : The width of the shallow water defense zone (SWDZ).

The crusing and the array deployment speeds for both aircraft types (the C-130 and the CH-53) are given below in Table 1 [Ref.2:p.24].

TABLE 1. SPEEDS OF THE AIRCRAFT USED IN AdDA DEPLOYMENT TACTICS

	AIRCRAFT TYPE	
	C-130	CH-53
Cruising Speed (S_t)	300 kts.	150 kts.
Deployment Speed (S_d)	125 kts.	60 kts.

As in the previous study, the distance between the base of the planes and the Datum will be taken as 300 miles, and the width (W) of the SWDZ is assumed to be 120 miles. These assumptions are also reasonable for the shallow water defense zones surrounding the Turkish Straits. Using the same assumptions will make the results of this analysis applicable for both U.S East Coast and Turkish Straits.

The mission of the submarine is assumed as either constructing a minefield in the SWDZ or carrying commando groups to the shoreline in this region.

The possible submarine speeds for the shallow waters will be taken as 5, 10, 15, and 20 knots in this study. It is not

necessary to consider higher speeds because of the presence of the "cavitation" effect. The high speed of a propeller causes a pressure change in the vicinity of the propeller which creates bubbles around it and noise in the water. Thus for a submarine in an intrusion mission to shallow waters, travelling above the cavitation speed is too risky; higher speeds can be used only for an emergency and escaping from the SWDZ.

The number of array segments that can be carried by each plane will be taken as 12 [Ref.2:p.22]. This number is based on the payload of each aircraft and the weight of array segments, which are proposed as 30 nm in length.

B. THE EFFECT OF THE DEPTH ON THE AdDA DEPLOYMENT TACTICS

An air-deployable fiber optic cable has to sink completely to the sea floor before activation [Ref.5:p.88]. In this thesis, air-deployable fiber optic cables (which were developed by the Naval Ocean Systems Center, and have similar technical properties with the AdDA) will be used as a reference for the sinking rate of the AdDA. The sinking rate of this cable is 0.024 fathom/second [Ref.5:p.87].

When considering deployment time, the type of the deployment platform becomes important. In the experiments done by the Naval Ocean System Center (Hawaii), C-130 and CH-53 aircraft were used for the deployment of this air deployable fiber optic cable, just as is assumed here for AdDA deployment

tactics. The AdDA deployment process can be summarized as follows.

1. The aircraft begins to deploy the AdDA segments. The cable hits the sea surface 6 nm behind the aircraft [Ref.5: p.89], and this end of the cable will be at 20 fathoms depth when deployment of an AdDA array segment (30 nm in length) is completed.

2. The time that passes between dropping the cable from the plane and the cable touching the sea surface, is small (for the C-130 this time is about 2.5 minutes), thus this time period is neglected in the calculations of the MOE's.

3. After the cable hits the water, it begins to sink with a sinking rate of 0.024 fathoms/second, or 86.4 fathoms/hour.

4. The air-deployable fiber optic cable is designed so that, when it is deployed, it will stay on the sea floor and will not change its position [Ref.5:p.90].

The sinking rate affects the performance of all the proposed deployment tactics, and thus the depth in the deployment area becomes critical. In this thesis the depth in the deployment area is assumed as constant for ease of analysis. For calculation purposes the sinking times of an AdDA array (which is 30 nm in length) are given in Table 2 for different deployment depths. These sinking times will be used in this thesis for the analysis of the effectiveness of the AdDA deployment tactics.

The activation time of an AdDA segment is represented by T_a and is equal to the sum of the deployment and the sinking times of an array segment ($T_a = T_{sk} + T_d$). The deployment time

of an AdDA array segment is 0.24 hour for the C-130, and 0.5 hour for the CH-53 (The deployment time for each aircraft is calculated from the deployment speed of the aircraft and the length of the AdDA array segment).

TABLE 2. THE SINKING TIMES OF THE AdDA CABLES TO THE SEA FLOOR	
AVERAGE DEPTH IN THE DEPLOYMENT AREA	SINKING TIME TO THE SEA FLOOR (T_{sk})
100 Fathoms	1.16 Hours
150 Fathoms	1.73 Hours
180 Fathoms	2.08 Hours
200 Fathoms	2.31 Hours

The analysis of the effect of depth on the proposed tactics will be given for each aircraft type separately.

1. Analysis for C-130

The numerical analysis for determining the MOE values will be done for both single and dual aircraft tactics, with the tactics in the same order as listed in Section C of Chapter II. During the analysis, the tactics will be summarized, and the figures in Chapter II will be used as reference.

a. *Arbitrary 50 NM. Placement for Single Aircraft*

For the Arbitrary 50 NM Placement tactic, four 30 nm AdDA array segments are needed to span the 120 nm width of the SWDZ. For a single aircraft the two spans are done sequentially, each beginning 50 nm from the datum. To evaluate

this tactic we must first consider the distance R that the submarine could travel during the total time necessary for an aircraft to cruise from its base to the deployment starting point, and to deploy five arrays. The first four arrays form the first span, deployed perpendicular to the shallow water defense zone border line (SWDZBL). After the plane completes the first span, it will fly at cruising speed to the second starting point, which is 100 nm away from the initial deployment starting point and also on the SWDZBL (as shown in Figure 4 in Chapter II). Then the fifth array segment will be deployed perpendicular to the SWDZBL. If the distance R that the submarine could travel during this total time is greater than 50 nm, then this proposed tactic does not provide certainty that the submarine will be between the spans in the shallow water defense zone. The distance R travelled by the submarine at speed S_e can be found by using Equation 1, where T_s is the time to arrive on station, T_a is the activation time (deployment and sinking to the sea floor) of the fifth AdDA array segment (or the first segment in the second span), and S_d and S_t are the deployment and the cruising speeds of the aircraft respectively.

$$R = S_e \times \left[T_s + \frac{W}{S_d} + \frac{(\sqrt{100^2 + W^2}\,)}{S_t} + T_a \right] \qquad (1)$$

The distance R is calculated for different submarine speed and deployment depth combinations. The submarine speeds that limit the tactic for various deployment depths (the depths are taken as the <u>average</u> deployment depth in the shallow water defense zone) are listed in Table 3. The tactic is considered "infeasible" if there is no certainty that the submarine will be captured by the two spans in the shallow water defense zone.

TABLE 3. PERFORMANCE OF THE ARBITRARY 50 NM PLACEMENT TACTIC FOR SINGLE C-130 AIRCRAFT

AVERAGE DEPTH IN THE DEPLOYMENT AREA	ARBITRARY 50 NM PLACEMENT TACTIC IS INFEASIBLE IF THE SUBMARINE SPEED IS GREATER THAN
100 Fathoms	13.4 Knots
150 Fathoms	11.7 Knots
180 Fathoms	10.8 Knots
200 Fathoms	10.2 Knots

In the previous study this tactic was found feasible for submarine speeds less than 18 knots. Table 3 shows, for example, that when we consider the sinking time for the AdDA cable, the Arbitrary 50 nm Placement tactic does not guarantee enclosure even for 12 knots of submarine speed and 150 fathoms deployment depth.

Another problem with the tactic is that there is also a chance for the submarine to reach its target and complete its mission without any detection by the AdDA cables.

The isolation area is 12,000 nm^2, and the isolation efficiency is 0.01 for submarine speeds of 5 and 10 knots, and for all deployment depths; therefore they will not be given in tabular form. The Arbitrary 50 NM Placement tactic will not be discussed for the slower CH-53.

b. Box the Farthest-On Region for Single Aircraft

The graphical representation of Boxing the Farthest-On Region tactic (Figure 5) was given in Section C of Chapter II. It differs from the Arbitrary 50 NM Placement tactic only in deployment starting points. If d1 represents the distance that the submarine could travel at speed S_c along the shallow water defense zone border line (SWDZBL) by the time the aircraft flies to the deployment starting point and activates (deploy the cable and the cable sinks to the sea floor) the first AdDA array segment perpendicular to the SWDZBL, and d2 represents the distance that the submarine at speed S_c could travel by the time the aircraft arrives at the starting point, deploys the array segments spanning the SWDZ of width W, transits to the other side of the Datum (lost point), and deploys an array segment perpendicular to the SWDZBL, then the total area covered by this tactic can be found by using Equation (2), which is

$$Area = (d1 + d2) W \quad . \tag{2}$$

By using the definitions given above, the d1 and d2 values in Equation (2) can be written as:

$$d1 = S_e \, (T_s + T_d + T_{sk}) \quad and, \tag{3}$$

$$d2 = S_e \left[T_s + \frac{W}{S_d} + \left(\frac{\sqrt{W^2 + (d1 + d2)^2}}{S_t} \right) + T_a \right] W \quad , \tag{4}$$

where S_t is the cruising speed of the aircraft, T_s is the time necessary for the aircraft to reach the starting point from its base, S_d is the deployment speed of the aircraft, and T_a is the activation (deployment and sinking) time of an AdDA array segment.

The gap (or the problem) in an Arbitrary 50 nm Placement is also present for the Boxing the Farthest-On Region tactic. This gap can be explained as: if the submarine travels on a course which is perpendicular to the shallow water defense zone border line, then it can reach its target (which is assumed as a minefield that will be constructed close to the coastline, or a location close to the shore, to send the commando groups) before detection by the AdDA array segments.

The area covered by this tactic and the isolation efficiency value are calculated for different submarine speed and depth combinations, and are given in Table 4.

TABLE 4. PERFORMANCE OF BOX THE FARTHEST ON REGION TACTIC FOR SINGLE AIRCRAFT C-130					
	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	3102	6235	9428	12704
	150	3788	7624	11543	15574
	180	4210	8477	12845	17342
	200	4488	9038	13702	18508
ISOLATION EFFICIENCY	100	0.043	0.022	0.015	0.011
	150	0.035	0.018	0.012	0.009
	180	0.032	0.016	0.011	0.008
	200	0.029	0.015	0.01	0.007

c. *Bound the Expanding Farthest-On Circle*

As was shown in Figure 6 in Chapter II, in the Bounding the Expanding Farthest-On Circle tactic the first AdDA array segment is deployed perpendicular to the shallow water defense zone border line, beginning at a distance d1 from the Datum. The rest of the array segments are deployed so that the end of the n^{th} array segment will be on the (n+1)st farthest-on circle of the submarine (this point will be called as intersection point). For each array segment if we draw a line connecting the Datum (lost point) to the intersection point, a triangle will be formed, using the array and the line from the Datum to the end of the previous segment. Then the isolation area can be found basically by summing the areas of these triangles. There is no intersection point for the first

array segment, and the area of the first triangle (which is a right-angled triangle) is (d1 L)/2.

For the array segments that will be deployed after the first array segment, the length D_n of the line which connects the Datum to the intersection point for the n^{th} array segment can be found from Equation (5); where S_e is the speed of the submarine, T_s is the time necessary for the aircraft to reach the starting point from its base, T_{sk} is the sinking time of one array segment to the sea floor, and T_d is the deployment time of the AdDA array segment:

$$D_n = S_e(T_s + T_{sk} + (n+1) T_d) \quad . \tag{5}$$

The boundary formed by the Bounding the Expanding Farthest-On tactic was drawn for each different submarine speed and depth combination (these drawings will not be given in this thesis). By examining each drawing, the number of AdDA array segments necessary to construct the tactic, and the isolation area were found for each submarine speed-deployment depth combination. The resulting isolation area and the isolation efficiency values are given in Table 5.

This proposed tactic was found feasible for all submarine speeds in the previous study [Ref.2:p.29]. Table 5 shows that when we consider sinking time for the AdDA array segment, the tactic becomes infeasible for some speed-deployment depth combinations. For the given assumption about

the width of the SWDZ in Section A (W=120 nm), this tactic is infeasible for all deployment depth values if the submarine speed is 10 and 15 knots, in that the submarine could reach the shore before being bounded by the spans, constructed by the AdDA arrays, in the SWDZ.

TABLE 5. PERFORMANCE OF BOUND THE FARTHEST-ON CIRCLE TACTIC FOR SINGLE AIRCRAFT C-130

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	490	N/A	N/A	N/A
	150	649	N/A	N/A	N/A
	180	796	N/A	N/A	N/A
	200	N/A	N/A	N/A	N/A
ISOLATION EFFICIENCY	100	0.68	-	-	-
	150	0.51	-	-	-
	180	0.42	-	-	-
	200	-	-	-	-

It is also observed that the definition of the tactic is very critical. To make the tactic feasible also for 10 and 15 knots of submarine speed it should be changed to the following.

1. The plane flies to the deployment starting point. The distance d1 between the starting point and the lost point is the maximum distance that the submarine could travel during the flight to the starting point, and the deployment and sinking of the first AdDA array segment.

2. The n^{th} farthest-on circle can be found from Equation (5).

3. The first array segment will be deployed perpendicular to the SWDZBL.

4. After the deployment of the first array segment, the rest of the AdDA array segments will be deployed so that the end of the n^{th} array will be a point on the (n+2)nd farthest-on circle of the submarine.

When the new definition is used the tactic appears feasible for all submarine speed-deployment depth combinations for aircraft C-130. Table 6 shows the isolation area and the isolation efficiency values for different deployment depth and submarine speed combinations, and illustrates that the tactic becomes feasible when the new definition is used for the tactic.

TABLE 6. *THE PERFORMANCE OF THE BOUND THE FARTHEST-ON CIRCLE TACTIC FOR C-130 WHEN THE NEW DEFINITION IS USED FOR THE TACTIC*

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	490	1425	3515	7256
	150	686	2110	5200	10394
	180	770	2500	6496	12682
	200	876	2850	7486	16390
ISOLATION EFFICIENCY	100	0.67	0.175	0.048	0.017
	150	0.486	0.118	0.028	0.011
	180	0.433	0.08	0.022	0.008
	200	0.381	0.07	0.017	0.006

d. *Arbitrary 50 NM. Placement for Dual Aircraft*

In the previous study [Ref.2:p.29], the Arbitrary 50 NM Placement tactic for dual aircraft was found feasible for all submarine speeds. Here, to show the effect of the depth in the deployment area on the pro_ ɔsed tactic, we will first find the distance d1 that the submarine could travel during the total time for an aircraft to arrive at its deployment starting point, deploy the first AdDA array segment perpendicular to the shallow water defense zone border line (SWDZBL), and allow the array segment to sink to the sea floor. If this distance is greater than 50 nm, then this tactic is not feasible for that particular depth and submarine speed. The distance d1 can be found by using Equation (3). The area covered by the deployment of this tactic is:

$$Area = S_e \times (\ 2\ d1\ )\quad , \tag{6}$$

where S_e represents the speed of the submarine.

The distance d1 is found for different submarine speed and deployment depth combinations, and given in Table 7.

This tactic is not feasible at an average deployment depth of 150 fathoms if the submarine speed is greater than 16.8 knots; and not feasible for a submarine speed of 20 knots if the average deployment depth is greater than 109 fathoms.

TABLE 7. THE DISTANCE THAT COULD BE TRAVELLED BY THE SUBMARINE DURING THE FLIGHT TO THE STARTING POINT, DEPLOYMENT AND SINKING OF THE FIRST AdDA ARRAY SEGMENT					
	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
Distance travelled by the submarine (nm)	100	12	24	36	48
	150	15	30	45	60
	180	17	33	50	67
	200	18	36	53	71

e. *Box The Farthest-On Region for Dual Aircraft*

Boxing the Farthest-On Region tactic was explained for single aircraft. With the assumption that each aircraft starts the deployment almost at the same time, the only difference for dual aircraft application of the tactic is that the deployment of the array segments will be completed at the same time by both aircraft. In this case the distances d1 and d2, as shown in Figure 5 in Chapter II, are equal, which results a smaller isolation area when compared to its single aircraft version. The isolation area can be found by using Equation (7), which is:

$$Area = [\ 2\ S_e\ (\ T_s + T_d + T_{sk}\ )\ ]\ W \quad . \tag{7}$$

The isolation area and the isolation efficiency values have been found for different deployment depth and isolation efficiency combinations and are given in Table 8.

TABLE 8. PERFORMANCE OF BOX THE FARTHEST-ON REGION TACTIC FOR DUAL AIRCRAFT C-130					
	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (square miles)	100	2880	5760	8640	11520
	150	3564	7128	10692	14256
	180	3984	7968	11952	15936
	200	4260	8520	12780	17040
ISOLATION EFFICIENCY	100	0.043	0.022	0.015	0.011
	150	0.035	0.018	0.012	0.009
	180	0.032	0.016	0.011	0.008
	200	0.029	0.015	0.01	0.007

f. Rapid Enclosure of the Farthest-On Region

The Rapid Enclosure of the Farthest-On Region tactic was proposed to isolate the submarine by deploying the array segments so as to defend against the submarine's direct approach to the coastline. This will be done by constructing a parallel barrier to the shallow water defense zone border line (SWDZBL). The graphical representation (Figure 7) of this tactic was given in Section C of Chapter II. Here we will explain a way to find the isolation area, considering the effect of the depth in the deployment area. If n' represents the number of AdDA array segments necessary to construct a barrier parallel to the SWDZBL, and n'' represents the number of the array segments that will be deployed by <u>each</u> aircraft perpendicular to the SWDZBL, then the n' and n'' can be found by

using Equation (9) and (10) respectively, where S_e is the speed of the submarine, T_s is the time necessary for the aircraft to reach the starting point from its base, T_d is the time necessary to deploy one cable, and T_{sk} is the sinking time of the cable to the sea floor. In both equations, if the result of division (the number of arrays) is not an integer, then the result should be rounded up to the next integer. The total number of arrays necessary to construct this pattern can be expressed as:

$$2\left[\textit{round up} \left(\frac{n'}{2} \right) + n'' \right] \quad . \tag{8}$$

The term n' should be first divided by 2 and then rounded up to the next integer because of the use of two aircraft in the deployment tactic. If the number of AdDA array segments n' necessary to construct a parallel barrier to the SWDZBL is odd, then each aircraft will deploy only $n'-1$ array segments. Here

$$n'' = (\textit{next integer}) \left[\frac{S_e (T_s + T_d + T_{sk}) + (S_e T)}{L} \right] \quad , \textit{where} \tag{9}$$

$$T = \left(\textit{Round up} \left(\frac{n'}{2} \right) \right) T_d \quad . \tag{10}$$

The isolation areas for different submarine speed and deployment depth combinations can be found by using Equation (11), which is

$$\textit{Area} = 2\, n''\, L\, S_e \,(T_s + T_d + T_{sk}) \quad . \tag{11}$$

In the Rapid Enclosure of the Farthest-On Region tactic, $n^{''}$ (the number of array segments that will be deployed by each aircraft perpendicular to the shallow water defense zone border line), could limit the tactic. When $n^{''}$ is multiplied by the length of the cable (30 nm), the result could be more than W, where W represents the width of the shallow water defense zone, which is 120 nm for both the Turkish Straits and the East Coast of US. This may make this tactic infeasible for some submarine speed and deployment depth combinations with the use of two aircraft. The isolation area and the isolation efficiency values are given in Table 9.

TABLE 9. PERFORMANCE OF RAPID ENCLOSURE OF THE FARTHEST-ON REGION TACTIC FOR DUAL AIRCRAFT C-130

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	720	1440	4320	5760
	150	891	3564	5346	10692
	180	996	3984	5976	11952
	200	1065	4260	6390	12780
ISOLATION EFFICIENCY	100	0.347	0.174	0.028	0.022
	150	0.281	0.047	0.023	0.009
	180	0.251	0.032	0.021	0.007
	200	0.235	0.029	0.019	0.006

g. Deep Water Envelope Parallel Enclosure

The Deep Water Parallel Enclosure tactic was proposed to construct first a parallel barrier to the shallow

water defense zone border line (SWDZBL) to protect the submarine's direct approach to the coastline, and then other barriers to enclose the submarine in the SWDZ. The graphical representation (Figure 8) of the tactic was given in Section C of Chapter II. The geometric figure constructed by the use of this tactic will either be a trapezoid or rectangle [Ref.2:p.32]. In either case the isolation area can be found by using the area formula of a trapezoid. To apply this formula, it is necessary to find the number of AdDA array segments that will be deployed by each aircraft, both perpendicular and parallel to the SWDZBL. If n' is the number of array segments necessary to be deployed by each aircraft perpendicular to the SWDZBL, and n'' is the number of array segments deployed by each aircraft to construct a parallel barrier to the SWDZBL, then n' and n'' can be found by using Equations (12) and (13) respectively. In both of the equations, if the result is not an integer, then it should be rounded up to the next integer. Here we have

$$n' = (\textit{next integer}) \frac{[\, S_e \times (\, T_s + T_d + T_{sk}\,)\,]}{L} \text{ , and} \qquad (12)$$

$$n'' = (\textit{next integer}) \frac{[\, S_e(\, T_s + T_d + T_{sk}\,) + S_e(\, n'\, T_d\,)\,]}{L} \qquad (13)$$

The height of the trapezoid is equal to the distance travelled by the submarine during the total time necessary for the planes reaching to the deployment starting

point (w' the assumption that the planes will be on the starting point almost at the same time), deploying the first AdDA array segments, and the time for the array segments sinking to the sea floor. If n, where n=n'+n'', represents the total number of arrays deployed by each aircraft, then the isolation area can be found by using Equation (16). The results from Equations (14) and (15) will be used as input in Equation (16), also d1 value can be found from Equation (3). In Equation (14) the term U represents the length of the upper base of the trapezoid. In Equation (15) the term L represents the length of the lower base of the trapezoid (that will be formed as a result of the deployment); also in Equation (15) the term (n-1) is used due to the fact that one array segment is incorporated in the initial farthest-on radius term d1 [Ref.2:p.33]. Here

$$U = 2 \, (n'' L) \ , \tag{14}$$

$$L = 2 \, [\, S_e \, (T_s + T_d + T_{sk}) + S_e [\, (n-1) \, T_d \,] \ , \ and \tag{15}$$

$$Area = \frac{d1}{2} \times (U+L) \ . \tag{16}$$

The isolation area and the isolation efficiency values have been calculated for different submarine speed and deployment depth combinations, and are given in Table 10.

h. *Triangular Cap (Tricap)*

In the Tricap tactic, the AdDA array segments will span the distance from the deployment starting point to the

shallow water defense zone border line while being tangent to the greatest farthest-on circle of the submarine, as shown in Figure 9 in Chapter II. In the previous study it was proposed [Ref.2:p.34] that the array segments form a tangent with the outermost farthest-on circle at the point, where the line segment that connects this point to the Datum (lost point) forms an angle of 45 degrees with the shallow water defense zone border line. The radius of the outermost farthest-on circle is half the length of one side of the isosceles triangular figure of the isolation area [Ref.2:p.34].

TABLE 10. PERFORMANCE OF DEEP WATER PARALLEL ENCLOSURE TACTIC FOR DUAL AIRCRAFT C-130

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	547	1469	4363	6797
	150	720	3020	5780	11440
	180	833	3174	6723	13891
	200	911	3987	7372	15180
ISOLATION EFFICIENCY	100	0.457	0.17	0.029	0.018
	150	0.347	0.055	0.022	0.009
	180	0.3	0.039	0.019	0.006
	200	0.274	0.031	0.017	0.005

If n represents the number of array segments that will be deployed by each aircraft, then the value of n can be found by using Inequality (17) below, where S_t is the cruising speed of the aircraft, T_s is the time necessary for the

aircraft to reach the starting point from its base, S_d is the deployment speed of the aircraft, and T_{sk} is the sinking time of the cable to the sea floor. This inequality is

$$n\,L \geq 2\,S_e\,[\,T_s + (\,n-1\,)\,T_d + (\,T_d+T_{sk}\,)] \quad . \tag{17}$$

In this inequality the deployment and the sinking of the first array segment guarantees the activation for the remaining n-1 array segments. Therefore the term n-1 is only multiplied by the deployment time (T_d) of one AdDA array segment. This inequality can be arranged and rewritten as:

$$n \geq [\,\frac{(\,2\,S_e\,(\,T_s+T_{sk}\,)}{(\,L - 2\,S_e\,T_d\,)}] \quad . \tag{18}$$

As shown in Figure 9 in Chapter II, the deployment starting point is not on the SWDZBL. The distance D between the starting point and the Datum (lost point) can be found by using Equation (19):

$$D = \sqrt{2}\,(\,S_e\,(\,T_s + (\,n-1\,)\,T_d + (\,T_d+T_{sk}\,)\,)\,)\,) \quad . \tag{19}$$

The area covered by this tactic (with the effect of the depth in the deployment area) can be found by using Equation (20):

$$Area = S_e^2\,[\,T_s + n\,T_d + T_{sk}\,)]^2 \quad . \tag{20}$$

The isolation area and the isolation efficiency values have been calculated for different submarine speed and deployment depth combinations, and are given in Table 11.

2. Analysis for CH-53

The same analysis as was done for C-130 aircraft, will now be carried out to see the effect of using CH-53 type aircraft on the performance of the AdDA deployment tactics (for both single and dual aircraft tactics), and in same order as it was done for the C-130 in the previous subsection. The cruising and the deployment speeds of the CH-53 are 150 knots

TABLE 11. PERFORMANCE OF TRIANGULAR CAP TACTIC FOR DUAL AIRCRAFT C-130

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	144	697	1568	3318
	150	221	1030	2678	5446
	180	276	1267	3672	N/A
	200	315	1624	4102	N/A
ISOLATION EFFICIENCY	100	3.57	0.381	0.169	0.055
	150	2.33	0.255	0.067	0.025
	180	1.86	0.206	0.055	-
	200	1.45	0.164	0.03	-

and 60 knots respectively [Ref.2:p.24]. With 60 knots, the deployment time of an AdDA array segment is 0.5 hour, which also affects the activation time T_a. The activation times

($T_a=T_d+T_{sk}$) for different deployment depths with the CH-53 are given in Table 12.

TABLE 12. AdDA ARRAY SEGMENT ACTIVATION TIME WHEN CH-53 USED AS DEPLOYMENT PLATFORM	
AVERAGE DEPLOYMENT DEPTH (fathoms)	ACTIVATION TIME ($T_a = T_d + T_{sk}$)
100	1.66 Hours
150	2.23 Hours
180	2.58 Hours
200	2.81 Hours

a. *Arbitrary 50 NM Placement for Single Aircraft*

When sinking times were considered, the Arbitrary 50 NM Placement tactic was found infeasible for the C-130 aircraft. The reason for the infeasibility was that the submarine could travel more than 50 nm during the total time necessary for an aircraft to cruise from its base to the deployment starting point, and deploy five arrays. The first four arrays formed the first span, deployed perpendicular to the shallow water defense zone border line (SWDZBL). After the plane completes the first span, it will fly at cruising speed to the second starting point, which is 100 nm away from the initial deployment starting point and also on the SWDZBL (as shown in Figure 4 in Chapter II). Then the fifth array segment will be deployed perpendicular to the SWDZBL. The same gap, which made the tactic infeasible for the C-130, is also true when the CH-53 is chosen as deployment platform. Thus no

further analysis will be done for this aircraft with the Arbitrary 50 NM Placement tactic.

b. Box the Farthest-On Region for Single Aircraft

The isolation area, which will be covered by using the Boxing the Farthest-On Region tactic with a single aircraft, can be found from Equation (2), where d1 represents the distance that the submarine could travel along the shallow water defense zone border line (SWDZBL) by the time the aircraft flies to the deployment starting point and activates (deploy the cable and lets the cable sinks to the sea floor) the first AdDA array segment perpendicular to the SWDZBL, and d2 represents the distance that the submarine could travel by the time the aircraft arrives to starting point, deploys the array segments spanning the SWDZ, transits to the other side of the Datum (lost point), and deploys the first array segment perpendicular to the SWDZBL. To find d1 and d2, S_t (cruising speed of the plane) will be taken as 150 knots, T_s (cruising time of the plane from its base to the starting point) will be taken as 2 hours, and T_d (the deployment time of an aircraft) will be taken as 0.5 hour. The area and the isolation efficiency values have been calculated for different submarine speed-deployment depth combinations and are given in Table 13.

Boxing the farthest-on region tactic is not applicable for some submarine speed-deployment depth combinations with two aircraft. The reason for this

infeasibility can be explained as: the submarine could travel out of the deployment pattern without passing over the active (deployed and sunk) array segment. This is basically because of the violation of the necessary condition, which is given in Equation (21) below.

$$(d1+S_e\, T_d)^2 \leq L^2+d1^2 \quad . \tag{21}$$

When the necessary condition is satisfied, then the tactic guarantees the enclosure of the submarine in the SWDZ, for the particular submarine speed-deployment depth combination. The necessary condition is also true for the other tactics.

TABLE 13. PERFORMANCE OF BOX THE FARTHEST-ON REGION TACTIC FOR SINGLE AIRCRAFT CH-53

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	6144	12452	19173	N/A
	150	6806	13885	N/A	N/A
	180	7232	14767	N/A	N/A
	200	7513	15347	N/A	N/A
ISOLATION EFFICIENCY	100	0.02	0.01	0.007	-
	150	0.018	0.009	-	-
	180	0.017	0.0085	-	-
	200	0.016	0.008	-	-

c. Bound the Expanding Farthest-On Circle

The geometric figure of the Bounding the Expanding Farthest-On tactic was drawn for each different submarine speed and deployment depth combination (these drawings will not be given in this thesis). By examining each drawing, the number of the AdDA array segments necessary to construct the tactic, and the isolation area were found for each submarine speed-deployment depth combination, as explained for the C-130 in the previous subsection. The isolation area and the isolation efficiency values are given in Table 14.

TABLE 14. PERFORMANCE OF BOUND THE FARTHEST-ON CIRCLE TACTIC FOR SINGLE AIRCRAFT CH-53

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	N/A	N/A	11340	N/A
	150	N/A	N/A	N/A	N/A
	180	N/A	N/A	N/A	N/A
	200	N/A	6472	N/A	N/A
ISOLATION EFFICIENCY	100	-	-	0.01	-
	150	-	-	-	-
	180	-	-	-	-
	200	-	0.022	-	-

In the previous study [Ref.2:p.28], Bound the Farthest-On Circle Tactic was found feasible for submarine speeds 5-20 knots. Table 14 shows us that the depth in the deployment area is very influential on the performance of this

tactic when the CH-53 used as deployment platform. It is also observed that the definition of this tactic is very critical (as it was for the C-130), and to make the tactic feasible the definition could be changed, as it was for C-130, so that the n^{th} array segment ends on the (n+2)nd farthest-on circle. For example, when the new definition is used, the tactic becomes feasible for submarine speed of 10 knots and 100 fathoms deployment depth, with an isolation area of 4557 nm^2 (6 array segments used).

d. Arbitrary 50 NM Placement for Dual Aircraft

In the previous study the Arbitrary 50 NM Placement tactic was found feasible for submarine speeds of 5 through 20 knots [Ref.2:p.36]. To show the effect of the depth in the deployment area on the performance of this tactic, we will first find the distance d1 that the submarine could travel during the total time for an aircraft to arrive at its deployment starting point, deploy the first AdDA array segment perpendicular to the SWDZBL, and allow that array segment to sink to the sea floor. If this distance is greater than 50 miles, then this tactic is not feasible for that particular depth and submarine speed. The distance d1 is found as before by using Equation (3). The values of d1 have been calculated for different submarine speed and deployment depth combinations, and are given in Table 15.

TABLE 15.	**DISTANCE (d1) THAT COULD BE TRAVELLED BY THE SUBMARINE DURING THE FLIGHT TO THE STATION AND DEPLOYMENT OF THE ARRAY SEGMENTS**				
	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
DISTANCE (NM) TRAVELLED BY THE SUBMARINE	100	18.3	36.6	54.9	73.2
	150	21.2	42.3	63.5	84.6
	180	22.9	45.8	68.7	91.6
	200	24	48.1	72.2	96.2

Using interpolation, the results in Table 15 suggest that this tactic is not feasible for the CH-53 when the submarine speed is greater than 13.7 knots at a deployment depth of 100 fathoms or more. The tactic was feasible for all speeds at 100 fathoms deployment depth when the C-130 was used as the deployment platform.

e. Box the Farthest-On Region for Dual Aircraft

In the Boxing the Farthest-On Region tactic with dual aircraft the distances d1 and d2, as shown in Figure 5 in Chapter II, are equal, which results a smaller isolation area when compared to its single aircraft version. The isolation area can be found by using Equation (7). In this tactic, the submarine could travel so that it could be out of the deployment pattern without passing over the active array segment, which is a violation of the necessary condition given in Equation (21). Therefore this tactic is not

applicable for some submarine speed and deployment depth combinations with two aircraft, as shown in Table 16.

TABLE 16. PERFORMANCE OF BOX THE FARTHEST-ON REGION TACTIC FOR DUAL AIRCRAFT CH-53

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	4392	8784	13176	N/A
	150	5076	10152	15228	N/A
	180	5496	10992	N/A	N/A
	200	5772	11544	N/A	N/A
ISOLATION EFFICIENCY	100	0.028	0.014	0,01	-
	150	0.025	0.012	0.008	-
	180	0.023	0.011	-	-
	200	0.021	0.01	-	-

f. Rapid Enclosure of the Farthest-On Region

In the Rapid Enclosure of the Farthest-On Region tactic, if n' represents the number of AdDA array segments necessary to construct a barrier parallel to the SWDZBL, and n'' represents the number of array segments that will be deployed by each aircraft perpendicular to the SWDZBL, then n' and n'' can be found by using Equation (9) and (10) respectively. In both equations, if the result of division (the number of arrays) is not an integer, then it should be rounded up to the next integer. The total number of arrays used in the tactic can be expressed as: 2[round up(n'/2)+n''].

The isolation areas have been calculated by using Equation (11), and are given in Table 17.

TABLE 17. PERFORMANCE OF RAPID ENCLOSURE OF THE FARTHEST-ON REGION TACTIC FOR DUAL AIRCRAFT CH-53

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	1098	4392	9882	N/A
	150	1269	5076	11421	N/A
	180	1374	5496	N/A	N/A
	200	1443	5772	N/A	N/A
ISOLATION EFFICIENCY	100	0.228	0.028	0.01	-
	150	0.197	0.025	-	-
	180	0.182	0.023	-	-
	200	0.173	0.022	-	-

As shown in Table 17, the Rapid Enclosure of the Farthest-On Region tactic is infeasible for some submarine speed and deployment depth combinations, due to the violation of the necessary condition, which was given in Equation (21).

g. *Deep Water Parallel Enclosure*

The geometric figure, constructed by the use of Deep Water Parallel Enclosure tactic, will either be a trapezoid or rectangle [Ref.2:p.32]. In either case the isolation area can be found by using the area formula of a trapezoid. To apply this formula, it is necessary to find the number of AdDA array segments that will be deployed by each aircraft, both perpendicular and parallel to the SWDZBL. If n'

is the number of array segments necessary to be deployed by each aircraft perpendicular to the SWDZBL, and n'' is the number of array segments deployed by each aircraft to construct a parallel barrier to the SWDZBL, then n' and n'' can be found by using Equation (12) and (13) respectively.

If n, where $n=n'+n''$, represents the total number of arrays deployed by each aircraft, then the isolation area can be found by using Equation (16). The isolation area and the isolation efficiency values for different submarine speed-deployment depth combinations are given in Table 18.

TABLE 18. PERFORMANCE OF DEEP WATER ENVELOPE PARALLEL ENCLOSURE TACTIC FOR DUAL AIRCRAFT CH-53

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	1021	4817	11661	N/A
	150	1240	5808	14971	N/A
	180	1383	6449	N/A	N/A
	200	1480	6883	N/A	N/A
ISOLATION EFFICIENCY	100	0.245	0.026	0.009	-
	150	0.202	0.022	-	-
	180	0.181	0.019	-	-
	200	0.169	0.018	-	-

Table 18 shows that the Deep Water Parallel Enclosure tactic is infeasible for some submarine speed and deployment depth combinations, again due to the violation of

the necessary condition to guarantee bounding, which was given in Equation (21).

h. Triangular Cap (Tricap)

In the Tricap tactic, the distance D between the deployment starting point and the lost point is a constraint (because AdDA deployment could be found to commence over land). The distance D depends on the width of the shallow water defense zone, and can be found by using Equation (20).

Table 19 shows the isolation area and the isolation efficiency values for different deployment depth and submarine speed combinations.

TABLE 19. PERFORMANCE OF THE TRICAP TACTIC FOR DUAL AIRCRAFT CH-53

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	335	1731	5991	N/A
	150	447	2735	N/A	N/A
	180	645	3114	N/A	N/A
	200	705	3375	N/A	N/A
ISOLATION EFFICIENCY	100	1.493	0.144	0.021	-
	150	1.119	0.061	-	-
	180	0.338	0.054	-	-
	200	0.355	0.049	-	-

C. THE COMPARISON OF THE PERFORMANCES OF THE DEPLOYMENT TACTICS WITH THE DEPLOYMENT PLATFORMS C-130 AND CH-53

Among the eight tactics investigated, some were not feasible for certain combinations of depth and submarine

speed. For each combination of depth-submarine speed, one tactic minimizes the isolation area, and one maximizes the isolation efficiency (or one tactic optimizes both). For each depth-speed combination, the optimal tactic and the aircraft type can be found from the preceding analysis.The results are summarized in Table 20. To keep this table more compact, following abbreviations are used to represent the proposed AdDA deployment tactics:

- TRI : Triangular cap,
- REFOR : Rapid enclosure of the farthest-on region,
- DWPE : Deep water parallel enclosure tactic,
- BFORS : Box the farthest-on region (single aircraft),
- BFORD : Box the farthest-on region (dual aircraft),
- A5PTS : Arbitrary 50 nm placement (single aircraft),
- A5PTS : Arbitrary 50 nm placement (dual aircraft), and
- BEFOC : Bound the expanding farthest-on circle.

In Table 20 we see that when the deployment depth is considered, as the deployment platform, the C-130 has superiority over the CH-53 in all the AdDA deployment tactics. Besides, when the operation cost of both deployment platforms is considered, the superiority of the C-130 becomes overwhelming. The one-hour flight costs are 1637 dollars/hour and 2000 dollars/hour for the C-130 and the CH-53 respectively [Ref.6].

Also, an important insight revealed in the analysis is that those deployment tactics that were proposed to prevent the forward progression of the submarine towards the coastline give smaller isolation area and bigger isolation efficiency values. The Triangular Cap (Tricap) tactic gives the best performance for almost all submarine speed and deployment depth combinations, although in other scenarios it might not feasible because it would begin over land.

TABLE 20. THE TACTIC AND AIRCRAFT TYPE WHICH GIVES THE OPTIMAL RESULTS FOR EACH SPEED-DEPTH COMBINATION

	AVERAGE DEPTH (fathoms)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	100	TRI C-130	TRI C-130	TRI C-130	TRI C-130
	150	TRI C-130	TRI C-130	TRI C-130	TRI C-130
	180	TRI C-130	TRI C-130	TRI C-130	REFOR C-130
	200	TRI C-130	TRI C-130	TRI C-130	REFOR C-130
ISOLATION EFFICIENCY	100	TRI C-130	TRI C-130	TRI C-130	TRI C-130
	150	TRI C-130	TRI C-130	TRI C-130	TRI C-130
	180	TRI C-130	TRI C-130	TRI C-130	BFORD C-130
	200	TRI C-130	TRI C-130	TRI C-130	BFORD C-130

D. THE EFFECT OF USING LONGER OR SHORTER AdDA CABLES IN PROPOSED DEPLOYMENT TACTICS

In this section, we will explore the effect of using longer or shorter cables on the effectiveness of the proposed AdDA deployment tactics. This analysis will be done using the C-130 as deployment platform, and at 150 fathoms of deployment depth. The assumptions given at the beginning of this Chapter (the SWDZ width is 120 nm, and the distance between the base of the aircraft and the deployment starting point is 300 nm) are also consistent for this analysis.

The weight of each AdDA array segment (cable), which is 30 nm in length, is approximately 2500 lbs. Thus, due to the maximum payload, each C-130 aircraft can carry only 12 AdDA cables [Ref.2:p.22]. In all the preceding analysis, the number of AdDA array segments needed to construct the tactics never exceeded the aircraft's capacity. In this analysis, the maximum number of AdDA cables that can be carried by each of the C-130 aircraft is found by using simple interpolation for cable lengths different than 30 nm.

The performance of the proposed tactics will be examined for cables which are 60, 40, 20 and 10 nm in length. This analysis, which examines the effect of using different lengths of AdDA cables in the proposed tactics, will be done both for single and dual aircraft with the same order and by using the same methodology given in the previous section. Therefore, for each deployment tactic, only a summary and the results of the

analysis will be given. Table 21 shows the number of AdDA cables (array segments) that could be carried by a C-130 aircraft, the deployment time (T_d), and the activation time ($T_a=T_d+T_{sk}$) for different AdDA cable lengths.

TABLE 21. SUMMARY OF THE AdDA CABLE PROPERTIES IF THEIR LENGTH IS DIFFERENT THAN 30 NM

CABLE LENGTH (NM)	Max. Number of Cables that could be carried by each aircraft	DEPLOYMENT TIME (T_d) of an AdDA CABLE	ACTIVATION TIME (T_a) of an AdDA CABLE
60	7	0.48 hour	2.21 hours
40	9	0.32 hour	2.05 hours
20	18	0.1 hour	1.83 hours
10	36	0.08 hour	1.81 hours

1. Arbitrary 50 NM Placement for Single Aircraft

As explained in the Section A, the Arbitrary 50 NM Placement tactic could be infeasible, because the submarine could travel more than 50 nm during the total time necessary for an aircraft to cruise from its base to the deployment starting point, and to deploy enough array segments to span the width of the SWDZ and begin a second span (deploy first array segment of the second span). Beginning from the starting point the first span will be formed perpendicular to the shallow water defense zone border line (SWDZBL). After the plane completes the first span, it will fly at cruising speed to the second starting point, which is 100 nm away from the

initial deployment starting point and also on the SWDZBL (as shown in Figure 4 in Chapter II). Then the additional array segment will be deployed perpendicular to the SWDZBL. Table 22 shows the minimum submarine speeds that result in infeasibility.

TABLE 22. PERFORMANCE OF ARBITRARY 50 NM PLACEMENT TACTIC FOR AIRCRAFT C-130 WITH THE USE OF DIFFERENT LENGTH OF AdDA CABLES

CABLE LENGTH (NM)	THE TACTIC IS INFEASIBLE FOR SUBMARINE SPEED (if greater or equal)
60	10.7 knots
40	11 knots
30	11.2 knots
20	11.5 knots
10	11.7 knots

When this tactic is used there is also a chance for the submarine to reach its target and complete its mission without detection by the AdDA cables. If this gap is not considered, we can conclude that shorter cables make this tactic applicable for slightly higher submarine speeds.

2. Box the Farthest-On Region for Single Aircraft

The isolation area, which will be covered by using Boxing the Farthest-On Region tactic for single aircraft, can be found as before from Equation (2). The isolation area and the isolation efficiency values have been calculated for various cable lengths, and are summarized in Table 23.

use of shorter AdDA cables increase the performance of this deployment tactic.

TABLE 23. PERFORMANCE OF BOX THE FARTHEST ON REGION TACTIC FOR SINGLE AIRCRAFT C-130 WHEN DIFFERENT CABLE LENGTHS ARE USED IN THE DEPLOYMENT					
	LENGTH OF THE CABLE (NM)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	60	4078	8208	12436	16787
	40	3884	7818	11840	15978
	30	3691	7428	11245	15170
	10	2395	7232	10948	14767
ISOLATION EFFICIENCY	60	0.031	0.0152	0.01	0.0075
	40	0.032	0.0159	0.0106	0.0078
	30	0.034	0.0168	0.0111	0.0082
	10	0.052	0.0173	0.0114	0.0085

3. Bound the Expanding Farthest-On Circle

Bounding the Farthest-On Circle tactic was proposed in the previous study [Ref.2:p.16] as: the first AdDA array segment is deployed perpendicular to the shallow water defense zone border line. The rest of the array segments are deployed so that the end of the n^{th} array segment will be on the (n+1)st farthest-on circle of the submarine (this point will be called as <u>intersection point</u>). For each array segment if we draw a line connecting the Datum (lost point) to the intersection point, a triangle will be formed. Then the isolation area can

farthest-on circle of the submarine (this point will be called as intersection point). For each array segment if we draw a line connecting the Datum (lost point) to the intersection point, a triangle will be formed. Then the isolation area can be found basically by summing the areas of these triangles. If n represents the number of array segments currently deployed, then for the n^{th} array segment the length D of the line, which connects Datum to the intersection point, can be found from Equation (5).

The analysis in the previous section, which was performed to show the effect of deployment depth on the performance of the Boxing the Farthest-On Circle tactic, showed us that the definition of the tactic is very critical when slower aircraft are used. The new definition for 30 nm cable was used to show that it makes the tactic applicable for all submarine speed and deployment depth combinations are considered. When we consider using different cable lengths in this tactic, the definition of the intersection point should be changed for each different cable length to obtain feasible results for all submarine speed and deployment depth combinations, and is a suitable topic for a future study.

4. Arbitrary 50 NM Placement for Dual Aircraft

As explained for single aircraft, the Arbitrary 50 NM Placement tactic is limited in feasibility with the submarine speed. The submarine could travel a distance R so that when

the first AdDA array segment activated (deployment and sinking to the sea floor) the submarine could be out of the deployment pattern without crossing an active array segment. This makes the tactic infeasible for some submarine speed and depth combinations. Table 24 shows the value of R for 20 knots submarine speed. As shown in the table, when longer cables are used, the submarine can travel a relatively longer distance, which indicates that the use of shorter cables gives better performance for this tactic.

TABLE 24. PERFORMANCE OF ARBITRARY 50 NM PLACEMENT TACTIC FOR SINGLE AIRCRAFT C-130 WHEN DIFFERENT CABLE LENGTHS ARE USED IN THE DEPLOYMENT

CABLE LENGTH (NM)	THE DISTANCE THAT COULD BE TRAVELLED BY THE SUBMARINE DURING THE ACTIVATION OF FIRST AdDA ARRAY SEGMENT (NM)
60	64
40	61
20	58
10	56

5. Box The Farthest-On Region for Dual Aircraft

In the dual aircraft version of Boxing the Farthest-On Region tactic the distances d1 and d2, as shown in Figure 5 in Chapter II, are equal. This results a smaller isolation area when compared to its single aircraft version. The values of d1 are given in Table 25 for different cable lengths.

TABLE 25.	**DISTANCE d1 THAT COULD BE TRAVELLED BY THE SUBMARINE IN BOXING THE FARTHEST-ON REGION TACTIC FOR DUAL AIRCRAFT WHEN DIFFERENT CABLE LENGTHS ARE USED IN THE DEPLOYMENT**			
CABLE LENGTH (NM)	THE DISTANCE (NM) TRAVELLED BY THE SUBMARINE WITH A SPEED OF			
	5 knots	10 knots	15 knots	20 knots
60	16.05	32.1	48.15	64.2
40	15.25	30.5	45.75	61
20	14.15	28.3	42.45	56.6
10	14.05	28.1	42.15	56.2

By using these distances, the isolation area (from Equation (7)) and the isolation efficiency values are found for each different cable length, and are given in Table 26.

TABLE 26.	**PERFORMANCE OF BOX THE FARTHEST-ON REGION TACTIC FOR DUAL AIRCRAFT WHEN DIFFERENT CABLE LENGTHS ARE USED IN THE DEPLOYMENT**				
	CABLE LENGTHS (NM)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	60	3852	7704	11556	15408
	40	3660	7320	10980	14640
	20	3600	7200	10800	14256
	10	3396	6792	10188	13584
ISOLATION EFFICIENCY	60	0.065	0.033	0.022	0.016
	40	0.055	0.023	0.015	0.012
	20	0.035	0.017	0.012	0.009
	10	0.025	0.013	0.008	0.006

Table 26 shows that shorter cables give smaller isolation areas for the Boxing the Farthest-On Region tactic with dual aircraft. Although there appears to be a trade-off between the isolation area and the isolation efficiency in this tactic, one should remember that the isolation efficiency measure is computed from the number of cables (AdDA array segments), rather than from their aggregate length.

6. Rapid Enclosure of the Farthest-On Region

In the Rapid Enclosure of the Farthest-On Region tactic we must first find the number of array segments that will be deployed both perpendicular and parallel to the shallow water defense zone border line (SWDZBL). If n' represents the number of AdDA array segments necessary to construct a barrier parallel to the SWDZBL, and n'' represents the number of the array segments that will be deployed by each aircraft perpendicular to the SWDZBL, then n' and n'' can be found by using Equations (9) and (10) respectively. The total number of arrays used in the tactic can be found from Equation (8). After the values of n' and n'' are found, the isolation area can be found by using Equation (11). The isolation area and isolation efficiency values for each cable length, are given in Table 27.

Table 27 shows that the isolation area decreases when the cable length decreases. Again, the apparent trade-off

between the isolation area and the isolation efficiency if the submarine speed becomes higher should be viewed with caution.

TABLE 27. PERFORMANCE OF RAPID ENCLOSURE OF THE FARTHEST-ON REGION TACTIC FOR DUAL AIRCRAFT WHEN DIFFERENT CABLE LENGTHS USED IN THE DEPLOYMENT

	CABLE LENGTH (NM)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	60	1926	3852	5778	15408
	40	1220	2440	7320	9760
	20	578	2312	5202	9248
	10	562	2248	4215	7868
ISOLATION EFFICIENCY	60	0.13	0.065	0.043	0.008
	40	0.205	0.102	0.017	0.013
	20	0.433	0.054	0.016	0.008
	10	0.222	0.032	0.012	0.005

7. Deep Water Parallel Enclosure

To find the isolation area in the Deep Water Parallel Enclosure tactic, it is necessary to find the number of AdDA array segments that will be deployed by each aircraft, both perpendicular and parallel to the shallow water defense zone border line (SWDZBL). If n' is the number of array segments necessary to be deployed by each aircraft perpendicular to the SWDZBL, and n'' is the number of array segments deployed by each aircraft to construct a parallel barrier to the SWDZBL, then n' and n'' can be found by using Equations (12)

and (13) respectively. If n, where $n=n'+n''$, represents the total number of arrays deployed by each aircraft, then the isolation area can be found by using Equation (16).

For the Deep Water Parallel Enclosure Tactic, the isolation area and the isolation efficiency values have been calculated for different cable length and submarine speed combinations, and are given in Table 28.

TABLE 28. PERFORMANCE OF DEEP WATER PARALLEL ENCLOSURE TACTIC FOR DUAL AIRCRAFT WHEN DIFFERENT CABLE LENGTHS ARE USED IN THE DEPLOYMENT

	CABLE LENGTH (NM)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (NM^2)	60	1336	3419	6247	16139
	40	916	2443	7290	11334
	20	532	2315	5625	10369
	10	518	1880	4845	9340
ISOLATION EFFICIENCY	60	0.187	0.073	0.04	0.024
	40	0.273	0.102	0.017	0.011
	20	0.47	0.054	0.015	0.007
	10	0.241	0.044	0.01	0.004

8. Triangular Cap (Tricap)

To see the effect of using different cable lengths in the Tricap tactic, the isolation areas have been calculated by using Equation (20). The isolation area and the isolation efficiency values for different cable lengths are given in Table 29.

TABLE 29.	PERFORMANCE OF THE TRICAP TACTIC FOR DUAL AIRCRAFT WHEN DIFFERENT CABLE LENGTHS ARE USED IN THE DEPLOYMENT				
	CABLE LENGTH (NM)	SUBMARINE SPEED			
		5 Kts	10 Kts	15 Kts	20 Kts
ISOLATION AREA (square miles)	60	258	1031	3064	6956
	40	233	1135	3064	6432
	20	232	1030	2555	5446
	10	208	980	2555	5213
ISOLATION EFFICIENCY	60	1.938	0.485	0.082	0.024
	40	2.146	0.22	0.054	0.019
	20	1.078	0.162	0.049	0.015
	10	1.202	0.102	0.025	0.009

Table 29 shows that the shorter cables give smaller isolation areas. If we want to isolate the hostile submarine in an area as small as possible, then we can conclude that the use of shorter cables improves the performance of the Tricap tactic.

E. THE EFFECT OF THE DEPTH ON THE DETECTION PROBABILITY OF AN AdDA ARRAY SEGMENT

The average depth in the deployment area affects not only the isolation area and the isolation efficiency of the deployment tactic, but also affects the detection probability of each AdDA array segment used in the deployment, and therefore the detection performance of the entire pattern. This idea can be illustrated with the help of Figure 10 and Figure 11.

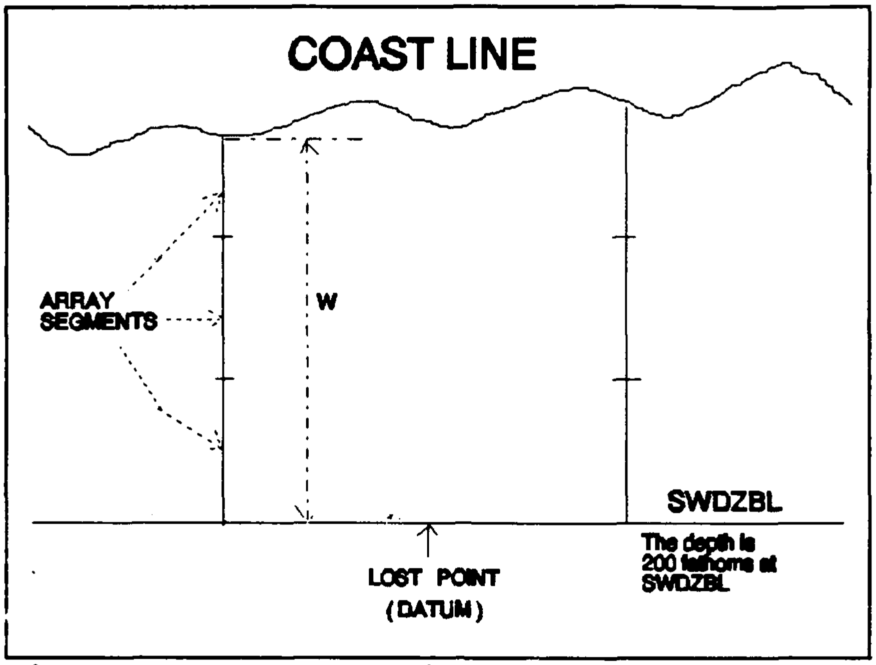

Figure 10. The graphical representation of the deployment area from top

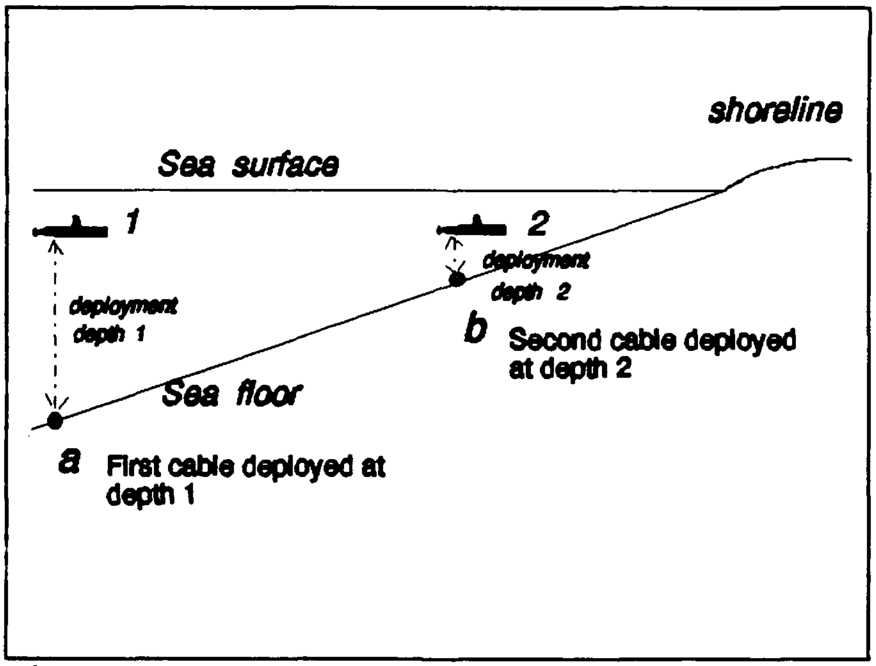

Figure 11. The representation of the profile of the deployment area

The effect of the magnetic field of the submarine on the AdDA array is not same at points a and b, which are shown in Figure 11. This results in different detection performance for each array segment. The submarine which is shown as Number 1 in Figure 11 has a smaller effect on the AdDA array segment than the submarine which is shown as Number 2.

The detection probability of the AdDA was accepted as 1.0 throughout the first study [Ref.2]. Although the design of the cables which are very similar to AdDA gives 30-120 days of estimated lifetime [Ref.5:p.87], the reliability of the cable can be affected to some extent during or after the deployment procedure. A simple model would be as follows. If P1 represents the highest value of the detection probability of the AdDA array segment which is deployed R1 nm from the coastline, and P2 represents highest value of the detection probability of the AdDA array segment which is deployed at a greater distance R2 nm from the coastline, then the change in the detection probability per nm can be written as:

$$CP = \frac{P1 - P2}{R2 - R1} \quad . \tag{22}$$

After the CP value is found, the detection probability of the array segment can be calculated by taking the average value of the probabilities for the endpoints of the array segment. If we assume P1 as 0.9 at a distance R1 which is 20 nm from the coastline, and the detection probability P2 at shallow water defense zone border line (SWDZBL) as 0.5 (in

this case the distance R2 is equal to the width of the shallow water defense zone, which is 120 nm) then the change in the detection probability per nm is found as 0.004.

IV. CONCLUSIONS AND RECOMMENDATIONS

Today fiber optics offer unique capabilities for solving some of the Turkish Navy's possible tactical problems in the future, as well as offering new lightweight cables, which are more easily deployed from an aircraft, flying at certain speeds for strategic surveillance. For example, the Advanced Air Deployable Array (AdDA), which is a modern air-dropped fiber optic ASW device, provides rapid enclosure of a hostile submarine in shallow waters and helps to regain contact with it. Besides, once it is deployed, it will stay active for 90 to 120 days. Therefore, it could provide a decrease in the number of ASW assets necessary to protect a certain shallow water defense zone against intrusion by hostile submarines. This could allow us to use those ASW assets in other critical missions. Due to constraints in the number of Turkish Navy ASW assets, this chance could be vital when the shallow water defense zones, which surround the Turkish Straits, are considered.

The analysis of a proposed set of alternate AdDA deployment tactics illustrates that given an initial set of conditions, the isolation area and the isolation efficiency can be found, and the tactics compared.

The activation of an AdDA array segment requires that it sink completely to the sea floor, which means that consideration of the deployment depth is important when evaluating the performance of these systems in the shallow water defense zone (SWDZ). When the deployment depth is considered in the analysis, the isolation areas become much bigger, compared to the previous study [Ref.2]. We can give an example from the Tricap tactic, which was found as the best performed AdDA deployment tactic: For an average deployment depth of 100 fathoms, the isolation area becomes almost 1.9 times bigger than that suggested when depth was not considered. The increments in the isolation area are 3, 3.8, and 4.5 times for 150, 180, and 200 fathoms of deployment depth respectively.

An important insight revealed in this analysis is that those deployment tactics that were proposed to prevent the forward progression of the submarine towards the coastline give smaller isolation areas and bigger isolation efficiency values when depth is considered.

As was shown in Table 20 in Section C of Chapter III, when the deployment depth is considered, the C-130 is superior to the slower CH-53 in all the AdDA deployment tactics. Besides, when the operation cost of both deployment platforms is considered, the superiority of the C-130 becomes almost overwhelming. The one hour flight costs for the C-130 and the CH-53 are 1637 dollars/hour and 2000 dollars/hour

respectively [Ref.6]. Also, as was shown in Table 20, the consideration of deployment depth eradicates the trade-off, which is revealed in the previous study [Ref.2:p.40], between the isolation area and the isolation efficiency for the 30 nm AdDA cable.

The analysis also supports the intuitive notion that, using cables shorter than 30 nm gives smaller isolation areas. Obtaining a smaller isolation area is extremely important, especially when the contact from the submarine is lost in the shallow water defense zone. For the AdDA deployment tactic with the best performance in this study, Tricap, the isolation area diminishes 5 percent with the use of 10 nm array segments at a deployment depth of 150 fathoms.

A continuation of the work reported here would be a stochastic model, which uses the prior known locations of the submarine. This could be used to estimate the submarine's course, and could help to direct the aircraft, which are used as the AdDA deployment platform, to a good starting point, saving much time just at the beginning of the search and the AdDA deployment. In such a stochastic model, the transition probabilities could be assigned for ASW purposes keeping the following in mind:

- The mission of the hostile submarine (from intelligence reports),
- The geographic properties of the region,

- Past historical data (similar submarine intrusion operations in history, especially from WWII), and

- Data, collected from two-sided exercises, which are performed by our own ASW and submarine forces by using an intrusion scenario in the shallow water defense zones of our special interest (like the Bosphorus).

Further analysis that would be useful is the incorporation of the proposed AdDA deployment tactics in high-fidelity simulation models to determine their marginal utility in affecting submarine prosecution. Also, a simulation could be performed for a stochastic model such as mentioned above, to estimate values for the probabilities of the submarine's course. Those probabilities will be quite helpful in finding the detection probability of an AdDA deployment tactic.

The Advanced Air Deployable Array (AdDA), which is basically an air-deployable fiber optic cable, may play a vital role in the defense of the shallow waters surrounding the Turkish Straits. It is also hoped that the ideas presented here will be useful in development of the AdDA deployment tactics which were proposed for the Air Defense Initiative Architecture (ADI) of North America.

APPENDIX

Table 30 and Table 31 summarize the results of the previous study [Ref.2]. To keep the tables more compact the following notation is used to represent the AdDA deployment tactics.

- TRI : Triangular cap,
- REFOR : Rapid enclosure of the farthest-on region,
- DWPE : Deep water parallel enclosure tactic,
- BFORS : Box the farthest-on region (single aircraft),
- BFORD : Box the farthest-on region (dual aircraft),
- A5PTS : Arbitrary 50 nm placement (single aircraft),
- A5PTS : Arbitrary 50 nm placement (dual aircraft),
- BEFOC : Bound the expanding farthest-on circle,
- N/A : None of the tactics are applicable with single or dual aircraft, for the particular submarine speed,
- I/A : Isolation area, and
- I/E : Isolation efficiency.

It is emphasized that the results in these two tables were obtained without consideration of depth or sinking rate, and assumed that the AdDA cables were activated immediately after deployment.

TABLE 30. PERFORMANCE OF THE AdDA DEPLOYMENT TACTICS WITH THE C-130 AS THE DEPLOYMENT PLATFORM, WHEN THE DEPLOYMENT DEPTH IS NOT CONSIDERED					
AdDA TACTIC		SUBMARINE SPEEDS (Knots)			
		5	10	15	20
TRI	IA	77	308	986	1752
	IE	6.49	1.62	0.253	0.143
REFOR	IA	372	744	1116	1488
	IE	0.896	0.448	0.224	0.168
DWPE	IA	232	556	971	1478
	IE	1.08	0.450	0.257	0.169
BFORS	IA	2306	4632	6992	9402
	IE	0.054	0.023	0.018	0.013
BFORD	IA	1488	2976	4464	5952
	IE	0.084	0.042	0.028	0.021
A5PTS	IA	12000	12000	12000	N/A
	IE	0.01	0.01	0.01	-
A5PTD	IA	12000	12000	12000	12000
	IE	0.01	0.01	0.01	0.01
BEFOC	IA	258	480	774	2064
	IE	1.29	0.694	0.323	0.121

TABLE 31. PERFORMANCE OF THE AdDA DEPLOYMENT TACTICS WITH THE CH-53 AS THE DEPLOYMENT PLATFORM, WHEN THE DEPLOYMENT DEPTH IS NOT CONSIDERED

AdDA TACTIC		SUBMARINE SPEEDS (Knots)			
		5	10	15	20
TRI	IA	313	1800	7200	N/A
	IE	1.6	0.139	0.017	N/A
REFOR	IA	750	3000	4500	9000
	IE	0.444	0.056	0.032	0.011
DWPE	IA	563	1500	4500	9000
	IE	0.444	0.167	0.028	0.011
BFORS	IA	4704	9552	14654	20100
	IE	0.027	0.013	0.009	0.006
BFORD	IA	3000	6000	9000	12000
	IE	0.042	0.021	0.014	0.01
A5PTS	IA	12000	N/A	N/A	N/A
	IE	0.01	-	-	-
A5PTD	IA	12000	12000	12000	12000
	IE	0.01	0.01	0.01	0.01
BEFOC	IA	779	1950	5737	13806
	IE	0.428	0.128	0.025	0.007

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